3. MEASUREMENT SYSTEM AND PROCEDURES

The purpose of this section is to provide a detailed summary of the measurement system, test procedures, UWB-signal sample space, signal generation details, and hardware limitations for this experiment.

3.1 System

The experimental setup (see Figure 3.1) was comprised of five segments – LMR source, UWB source, continuous-wave (CW) source, noise source, and radio receiver. The system configuration is illustrated in Figure 3.2. Each of the wideband sources (i.e., noise and UWB) were filtered, amplified, and combined prior to input into the receiver. Signal powers were controlled using precision variable attenuators (VA1, VA2, and VA3). The following subsections provide signal-generation details and justification for hardware employed.

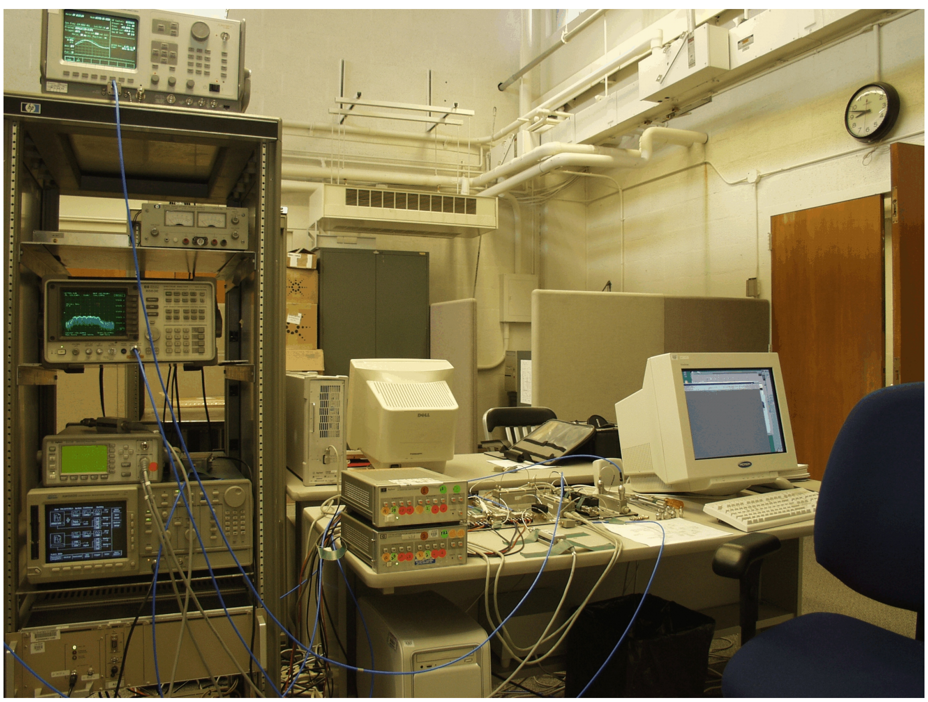

Figure 3.1. Public Safety radio interference test bed.

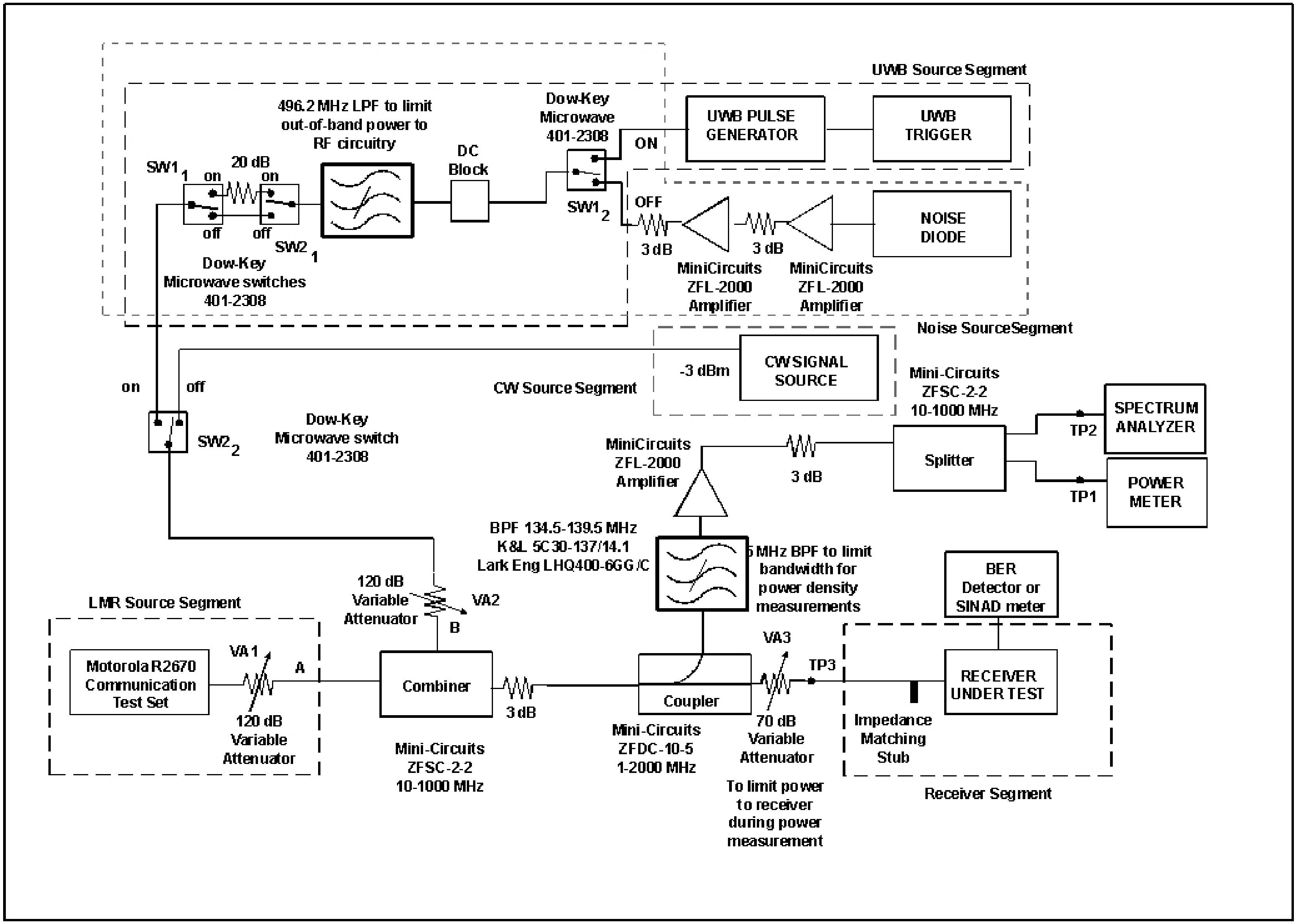

Figure 3.2. Block diagram of measurement system.

3.1.1 LMR Source Segment

The purpose of the LMR signal segment is to provide an emulated Public Safety LMR radio signal. The LMR signal was generated with a Motorola R-2670 Communications Test Set, the output being a digital test tone using a 1.011-kHz CW bit pattern with C4FM modulation. Figure 3.3 shows a frequency histogram of the generated signal as measured on a modulation domain analyzer (all equipment referenced with a rubidium oscillator). The analog test signal was generated by using a 1.0-kHz modulating signal and setting the maximum frequency deviation to 3 kHz. The center frequency for both signal types was 138 MHz. The R-2670 Communication System Analyzer served the additional role of a SINAD meter for analog testing.

3.1.2 UWB Source Segment

The UWB segment consists of a narrow-pulse generator and a triggering device (either an arbitrary waveform generator or a custom built relative-referenced triggering device) to create various signals. Because the pulse shape/width of the UWB signal determines the spectral envelope of the signal, the primary criterion for choosing a UWB pulse generator for these measurements was whether the spectral envelope has no nulls and produces sufficient power across the 138-MHz band of interest.†

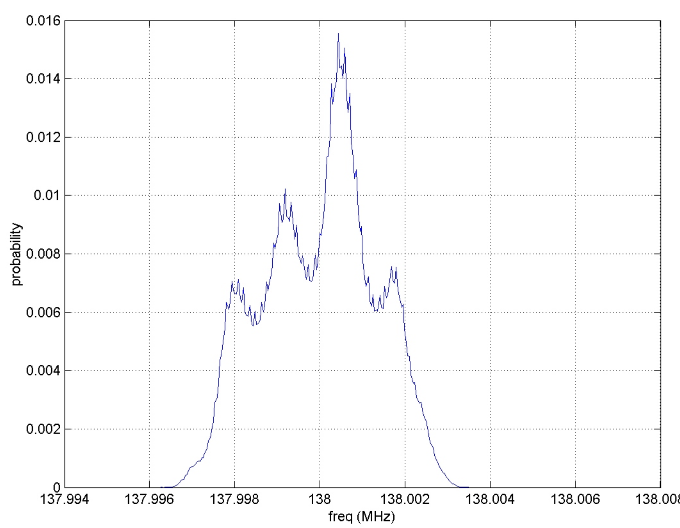

Figure 3.3. Frequency histogram of the C4FM modulated signal.

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†The UWB pulse generator used in these measurements is a Time Domain PG-2000 with impulse voltage rise time (10 - 90%) = 200 ps, impulse fall time (90 - 10%) = 416 ps, impulse width (50%) = 521 ps, and no nulls in the 138-MHz band.

UWB Signal Space

For these measurements, the UWB signal is specified by a combination of mode-of-spacing, PRF, and the application of gating. By varying these three parameters, 11 different permutations were chosen to span a reasonable range of existing and potential UWB signals. For these measurements (as shown in Table 3.1) there are two PRFs (0.1 and 20 MHz), four pulse spacing modes (UPS, OOK, 50%-ARD, and 2%-RRD), and two gating scenarios (no gating and 20% gating with a 4 ms on-time). In addition to these 11 permutations, for measurements with C4FM modulated transmissions, each of the UWB signals with spectral lines have two separate conditions of spectral alignment in relation to the spectral bins noted in Figure 3.3 – one with a spectral line at 138.000506 MHz (aligned with a C4FM frequency shift) and the other with a spectral line at 137.999862 (offset from any C4FM frequency shift). Three of the interference signal types were added as the measurements were in progress, and therefore, were only included with the measurements on one of the receivers; these additional UWB signal types consisted of: 1) 100-kHz PRF, UPS, gated, aligned, 2) 100-kHz PRF, UPS, gated, offset, and 3) 100-kHz PRF, ARD, gated.

Table 3.1. UWB Signal Space

PRF	Pulse Spacing Mode	Gating	Spectral Alignment
100 kHz	UPS	None	Aligned
100 kHz	UPS	None	Offset
100 kHz	UPS	Gated	Aligned
100 kHz	UPS	Gated	Offset
100 kHz	OOK	None	Aligned
100 kHz	OOK	None	Offset
100 kHz	ARD	None	N/A
100 kHz	ARD	Gated	N/A
100 kHz	RRD	None	N/A
20 MHz	UPS	None	Aligned
20 MHz	UPS	None	Offset
20 MHz	UPS	Gated	Aligned
20 MHz	UPS	Gated	Offset
20 MHz	OOK	None	Aligned

Con't Table 3.1. UWB Signal Space

PRF	Pulse Spacing Mode	Gating	Spectral Alignment
20 MHz	OOK	None	Offset
20 MHz	RRD	None	N/A
20 MHz	RRD	Gated	N/A

3.1.3 CW Source Segment

The CW source segment simply consists of a sinusoidal signal produced by a signal generator. The purpose of this segment is to emulate a single spectral line so as to compare the resulting interference to UWB signals also with spectral lines.

3.1.4 Noise Source Segment

The noise source segment consists of Gaussian noise produced by a noise diode. The purpose of this segment is to emulate Gaussian noise interference so as to compare the resulting interference to UWB signals that also have Gaussian noise-like characteristics.

3.1.5 LMR Receiver Segment

Two receivers, A and B, from two different Project 25 (P25) radio manufacturers, were used for measurement. Both receivers were programmed and tested in the P25 digital mode with a 12.5-kHz bandwidth, transmitting in the 138-MHz band. In addition, receiver B was, at a later point, programmed and tested in an analog FM mode, also with a carrier frequency of 138 MHz. Via network analyzer, each device was characterized for input impedance with the radios set to the 138-MHz band. So as to match (zero-reflection) the input impedance to the characteristic impedance of the 50 Ω cables, matching stubs were designed and placed at the antenna input of each radio receiver during measurements. Using a network analyzer to make measurements, Figures 3.4 and 3.5 show the resulting input impedance with the matching stubs in place. From these diagrams, it is clearly seen that the receivers' antenna inputs (after inserting the matching stubs) were closely matched to 50 Ω real impedance with essentially no imaginary component. So as to reduce any coupling of radiated emission into the receivers, each receiver was placed in a shielded box during measurements.

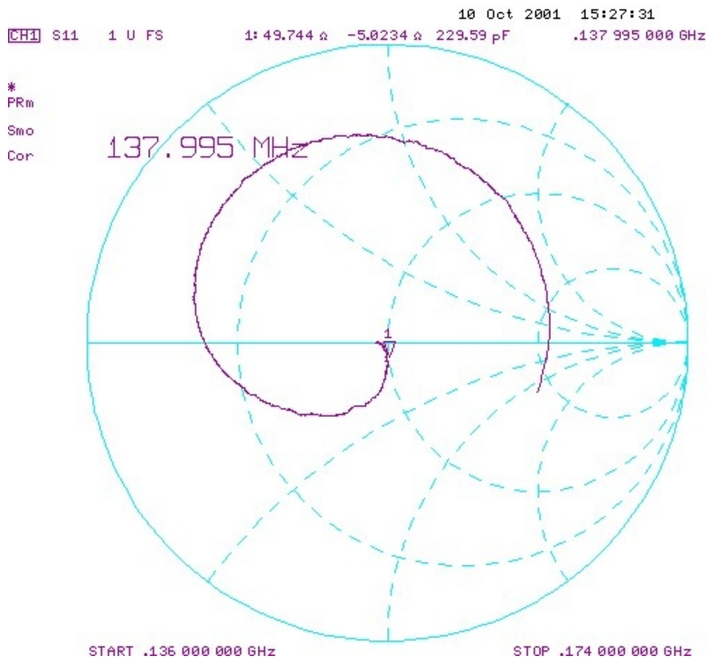

Figure 3.4. Input impedance to receiver A as seen at the input to the matching stub.

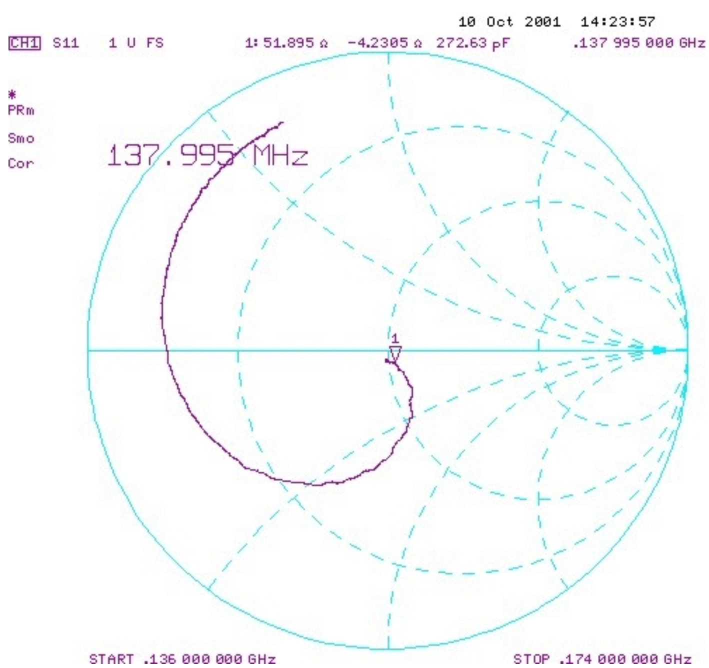

Figure 3.5. Input impedance to receiver B as seen at the input to the matching stub.

3.2 Measurement Procedure

The measurements are performed using the test setup as shown in Figure 3.2. The unwanted signal (UWB, CW, or Gaussian noise) is filtered, amplified, combined with the desired LMR signal, and injected into the Public Safety radio receiver at the antenna port of the receiver under test. Each of the individual signals (unwanted and desired) is independently measured for power using a power meter, with power translated (using calibration factors) to that at the input of the LMR receiver antenna port. For the digital-modulation receivers, measurements are conducted using a 5% BER performance threshold with a UWB signal, CW signal, and Gaussian noise (each separately) as the interfering source. For the analog FM receiver, the same interfering sources are used, but susceptibility measurements are conducted using a 12-dB SINAD performance threshold.

3.2.1 Digital-modulation (P25) Radio Receiver Measurement Procedure

The digital modulation (P25) radio receivers are tested using the process defined in the Project 25 Standards document TIA/EIA-102.CAAA [5]. The procedure described, however, is modified by replacing the description of co-channel interference rejection with in-band interference rejection and making additional desired-signal to interference ratio measurements.

The in-band interference rejection is the ratio of the reference sensitivity to the level of an unwanted input signal. The unwanted signal has an amplitude that causes the BER produced by a wanted signal 3 dB in excess of the reference sensitivity (see definition in step 2 below) to be reduced to the standard BER (in this case, 5%). The method of measurement is described as follows:

1. ***System configuration***: The measurement setup is configured as illustrated in Figure 3.6, with the unwanted signal source connected to terminal B of the combining network.

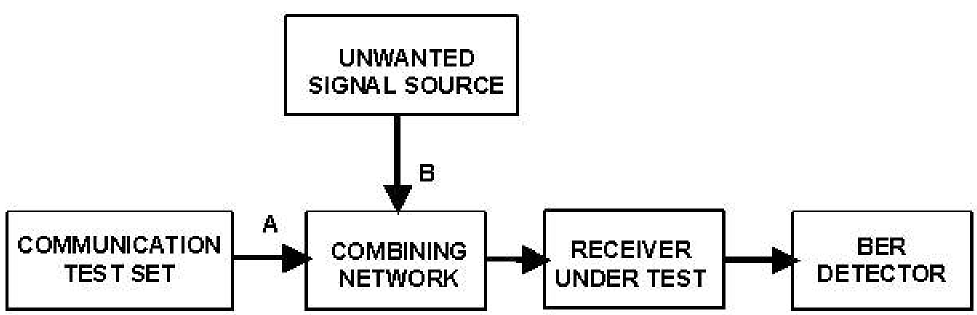

Figure 3.6. Basic block diagram for digital modulation radio receiver measurement.

2. ***Reference power of desired signal in absence of the interfering signal***: In the absence of the unwanted signal (VA2 set to maximum attenuation), the standard 1.011 kHz C4FM modulated tone is applied to terminal A of the combining network. The signal level is reduced to obtain reference sensitivity, defined as the minimum acceptable performance level (MAPL) without an interfering signal. [Note: For P25 receivers, the MAPL occurs with a BER of 5%.] This level is recorded in dBm as P_{REF}.

3. ***Performance versus variable interference power density in the presence of a static desired signal power***:
   a. The level of the wanted input signal is increased by 3 dB and the BER value recorded.
   b. The unwanted input signal (UWB, noise, or CW signal) is applied to terminal B of the combining network.
   c. The unwanted input signal power is increased to reestablish the MAPL. This level is recorded in dBm as P_I.
   d. The in-band interference rejection is calculated as follows:

      $$\textit{in-band interference rejection} = P_{REF} - P_I.$$

   e. The unwanted input signal power is reduced 10 dB in 1-2 dB steps. The level of the unwanted input signal is recorded along with the corresponding value of BER at each step.

4. ***Performance versus variable desired signal power in the presence of a static interference power density***:
   a. The unwanted input signal power is reduced to reestablish the MAPL (P_I).
   b. The level of the wanted input signal is increased approximately 10 dB in 1-2 dB steps. The level of the wanted input signal is recorded along with the corresponding value of BER at each step.

3.2.2 Analog FM Radio Receiver Measurement Procedure

The analog FM radio receivers are tested using a modified version of the process as defined in the FM/PM Standards document TIA/EIA-603. [6] The procedure described, however, is modified by replacing the description of adjacent-channel interference rejection with in-band interference rejection and making additional desired-signal to interference ratio measurements.

Once again, the in-band interference rejection is the ratio of the reference sensitivity to the level of an unwanted input signal. The unwanted signal has an amplitude that causes the SINAD produced by a wanted signal 3 dB in excess of the reference sensitivity (see definition in step 2 below) to be reduced to the standard SINAD (in this case, 12 dB). The method of measurement is described as follows:

1. ***System configuration***: The measurement setup is configured as illustrated in Figure 3.7, with the unwanted signal source connected to terminal B of the combining network.

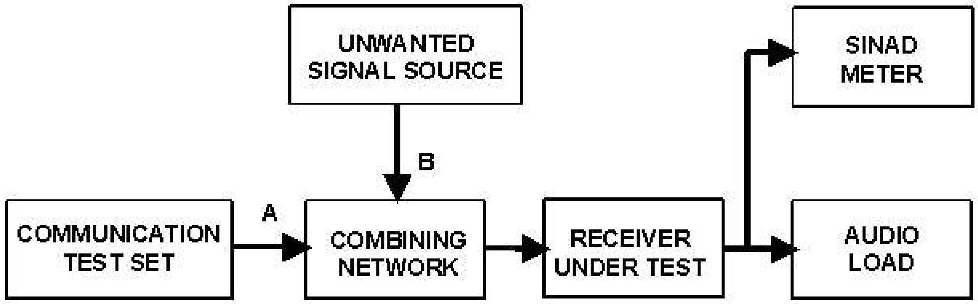

Figure 3.7. Basic block diagram for analog radio receiver measurement.

2. ***Reference power of desired signal in absence of the interfering signal***: In the absence of the unwanted signal (VA2 set to maximum attenuation), the standard 1.0-kHz FM modulated tone (3-kHz maximum frequency deviation) is applied to terminal A of the combining network. The signal level is reduced to obtain MAPL without an interfering signal. [Note: For Public Safety analog FM receivers, the MAPL occurs with a SINAD of 12 dB.] This level is recorded in dBm as P_{REF}.

3. ***Performance versus variable interference power density in the presence of a static desired signal power***:
   a. The wanted input signal power is increased by 3 dB and the SINAD value recorded.
   b. The unwanted input signal (UWB, noise, or CW signal) is applied to terminal B of the combining network.
   c. The unwanted input signal power is increased to reestablish the MAPL. This level is recorded in dBm as P_I.
   d. The in-band interference rejection is calculated as follows:
      in-band interference rejection = $P_{REF} - P_I$.
   e. The unwanted input signal power is reduced 10 dB in 1-2 dB steps. The level of the unwanted input signal is recorded along with the corresponding value of SINAD at each step.

4. ***Performance versus variable desired signal power in the presence of a static interference power density***:
   a. The unwanted input signal power is reduced to reestablish the MAPL (P_I).
   b. The wanted input signal power is increased approximately 10 dB in 1-2 dB steps. The level of the wanted input signal is recorded along with the corresponding value of SINAD at each step.

Because of receiver differences with regard to the way BER and SINAD are determined, there are some variations in sample size between the different receivers and their modulation modes. The bit errors for Receiver A are reported for each consecutive set of 1728 bits. A minimum of 20 of these values were recorded, averaged, and then divided by 17.28 to give a percent bit error. The bit errors for Receiver B in P25 mode are reported for each consecutive set of 96,960 bits. The percent bit error, therefore, was determined by reading a value from the device and then dividing by 969.6. The SINAD value for Receiver B in analog mode is determined by an analog SINAD meter located in the communication test set. A large enough population was sampled to give a standard deviation of 1 dB in interference signal power.

3.3 Power Measures, Settings, Calibration and Frequency Precision

The purpose of this section is to clarify power measurement terminology, discuss power level settings of the various signal sources, and describe the calibration procedures used to assure the proper power levels.

3.3.1 Calibration and Power Level Correction

For these measurements, all signal powers were measured with a thermoelectric power meter and expressed as a mean value. Wideband sources, such as UWB signals and noise, are expressed in terms of power density in a 1-MHz bandwidth (centered at 138 MHz). This section describes the various steps taken to assure power-level accuracy.

To assure that no test-fixture amplifier became saturated throughout the measurements and to verify functionality, powers were measured (via power meter) throughout the test fixture using the full range of signals and levels that exceeded those used during the measurements. Amplifiers, in addition, were tested for input-to-output linearity – also using the same range of signals and powers.

At the beginning of each day of measurement, calibrations were performed to verify proper operation and to determine a correction factor for proper referencing. As noted in Figure 3.2, the power is measured at the input to the power meter at point TP1. However, the results are reported in terms of the power at the input to the device under test at point TP3. The correction factor used to compensate for the difference in gains between these two paths is obtained by measuring, at these two points, the power of a 138-kHz CW signal supplied by the signal generator at switch SW2 and then adding the difference to each of the powers measured at TP1. During these calibration measurements, attenuation is set to 0 dB at VA3 and maximum at VA1.

Because of the manner in which the interfering power is typically stated in regulatory documents, UWB power is reported in these measurements as the power transmitted across a 1-MHz “brick-wall” bandpass filter centered at 138 MHz, giving a value stated here as the 1-MHz Bandwidth Power Density (1-MBPD). The actual filter (5-MHz bandpass filter) used has a more gradual rolloff and a bandwidth wider than 1 MHz. The correction factor used to compensate for the difference in transmitted power between these two filters is obtained by first measuring, via spectrum analyzer, the squared frequency amplitude response of the "actually-used" filter for each wideband interfering signal (UWB signal and Gaussian noise). To obtain the transmitted power received through the filters, the resulting functions for each of the wideband signals are integrated over the entire band between the stopbands of the "actually-used" filter and then once again across a 1-MHz bandwidth centered at 138 MHz. The correction factor for each wideband signal is the difference in dB of the transmitted power through the "actually-used" filter and the "brick-wall" filter.

Another issue regarding power settings has to do with measuring and setting the power of gated signals. Because the reaction time of a power meter is too fast to allow accurate measurement of gated signals, the power meter was configured to average 20 separate readings; this procedure (empirically determined) stabilized the output of the meter and showed values consistent with the non-gated case – a difference of 7 dB. (Twenty percent gating reduces mean non-gated signal power by 7 dB.) The power of all gated signals used during these interference measurements is expressed, depending upon the circumstance, as either the average power or the average power of the equivalent non-gated signal (i.e., the power of the gated-on time portion of the signal).

3.3.2 Frequency Precision

Because it is necessary to precisely place spectral lines of the interfering signals in relation to the spectral features of the desired signal (within a few tens of Hz), it is necessary to reference several instruments with a single oscillator. For these measurements, a rubidium oscillator was used to reference the AWG, the desired signal source (Motorola Communications Test Set), the CW signal source, and the spectrum analyzer.